

# Logic and probabilities for recommender systems

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# Contents

- Tourism recommenders as a case study
- Input and output
- Which probabilities we need?
- Simple layered semantics
- Cumulating evidence
- Rankings via meta-logical calculations

# Recommender systems?

- Several historical „expert systems“ were recommender systems (medicine etc)
- Google is a popularity-focused recommender
- Social network systems are recommender systems: recommend news items and possible friends and topics
- The wealth of data available online makes it possible to create recommenders for any kinds of tasks and goals

# Two main recommender types

- Collaborative filtering
- Rule-based, also called content-based

# Our tourism recommender project

- <http://www.sightsplanner.com>
- <http://www.sightsmap.com>



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27.03.2011

12:57

**Tallinn**

## Sightsp planner

The best guide to town

Each visit is unique: plan your trip to Tallinn just the way you like it

[How to use?](#)

### Walk in the city

Nice walk around the medieval Old town, history and cafes

[Choose](#)

### Active life

Great events, spiced with sports and outdoor activities

[Choose](#)

### A night in the town

Clubs, pubs, party and dancing all night long!

[Choose](#)

### Culture

Beautiful architecture, amazing paintings and concerts

[Choose](#)[Get your plan](#)[or see what's popular](#)

Less

More

+ Events

+ Museums &amp; Arts

+ Architecture &amp; City

+ Eating out

+ Shopping

+ Sports &amp; Outdoor

+ Bars &amp; Nightlife

Time 14:00

28.03.2011

Duration 1h 2h 3h 6h 8h

by car on foot



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Less

More

+ Events

- Museums &amp; Arts

Modern art gallery ☒ ☐ ☐

Installation, Happening ☒ ☐ ☐

Old history museum ☒ ☐ ☐

Science museum ☒ ☐ ☐

Classical art exhibition ☒ ☐ ☐

Other art ☒ ☐ ☐

Contemporary history ☒ ☐ ☐

Nature museum ☒ ☐ ☐

+ Architecture &amp; City

- Eating out

Traditional restaurant ☒ ☐ ☐

European restaurant ☒ ☐ ☐

Fine dining ☒ ☐ ☐

Fast food ☒ ☐ ☐

Asian restaurant ☒ ☐ ☐

Other restaurant ☒ ☐ ☐

Pub ☒ ☐ ☐

Cafe ☒ ☐ ☐



Time 14:00

29.03.2011



Duration 1h 2h 3h 6h 8h

by car on foot



## 1. Estonian History Museum - Great Guild Hall [Read more](#) [Locate on map](#)

Museums and Arts: Architecture and City: Old history museum: Medieval architecture:

In the course of time, the Great Guild Hall has played an important role in the life of the city. The permanent exhibition of the History Museum located in the building introduces Estonia's history...

Arrive 14:05

Stay

**45**

minutes

[Remove from selection](#)

Walk 5 minutes



## 2. Katarina käik (St Catherine's Passage) [Read more](#) [Locate on map](#)

Landmark: Architecture and City: Medieval architecture:

Vene and Müürivahe Streets are connected by Katarina käik. You can see the remaining parts of St Catherine's Church in its northern end. The southern part of the passage is lined by residenti...

Arrive 14:55

Stay

**20**

minutes

[Remove from selection](#)

Walk 5 minutes



## 3. Olde Hansa [Read more](#) [Locate on map](#)

Eating out: Traditional restaurant:

Olde Hansa Restaurant

[See more](#)

Arrive 15:20

Stay

**60**

minutes

[Remove from selection](#)

Walk 10 minutes





Tallinn

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[See Tallinn in context](#) [Start your Tallinn tour](#) [Join the Tallinn tour](#)

The itinerary below is based on your category preferences, start time, duration and means of transport. This is matched with the information about sights, their types, opening times, location, typical visit time and popularity of the sights.

To see more information for an object, click the 'Read more' or 'Location map' link. The map with all the suggested objects is below the itinerary and the predicted travel time is shown between the objects.

You can remove suggestions by clicking the 'Remove from itinerary' link. You can set the time at each object by clicking the number of minutes next to each object. If you have changed the stay time on objects or removed some objects from the itinerary, click the 'Suggest more' button to get a fresh itinerary with the new suggestions.

Suggest more

[Remove from itinerary](#) [Add to itinerary](#)

Time: 14:00

Date: 28.05.2014

Duration:

12:00

12:00

1. Katerina kähk (St Catherine's Passage) [Read more](#) [Location map](#)
[Remove from itinerary](#) [Add to itinerary](#)

Vene and Muirvõrre Streets are connected by Katerina kähk. You can see the remaining parts of St Catherine's Church in its northern and The southern part of the passage is lined by restaurants...

Travel 5 minutes

Arrive 14:05

Stay

20 minutes

[Remove from itinerary](#)
2. Kõrge [Read more](#) [Location map](#)
[Remove from itinerary](#) [Add to itinerary](#)

Kõrge is a small square in the Old Town of Tallinn. It is a small square in the Old Town of Tallinn. It is a small square in the Old Town of Tallinn.

Travel 5 minutes

Arrive 14:10

Stay

20 minutes

[Remove from itinerary](#)
3. Western Yard (Lääne aed) [Read more](#) [Location map](#)
[Remove from itinerary](#) [Add to itinerary](#)

This small courtyard in the Old Town is a little piece of Tallinn as it was centuries ago when people appreciated the work of craftsmen, who put their heart and soul into everything they made. This...

Travel 5 minutes

Arrive 14:15

Stay

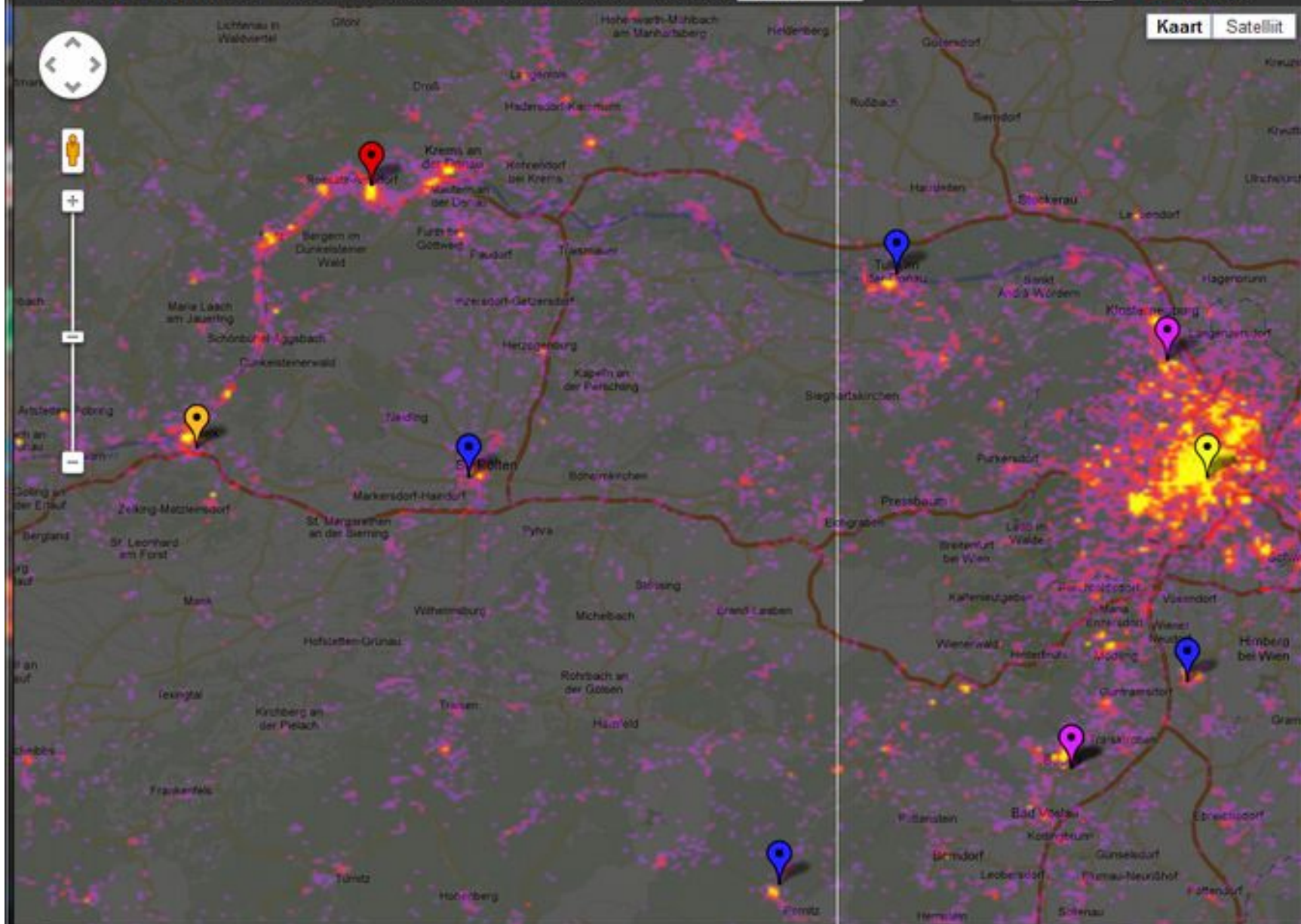
20 minutes

[Remove from itinerary](#)
4. Town Hall Square (Raekoja plats) [Read more](#) [Location map](#)
[Remove from itinerary](#) [Add to itinerary](#)

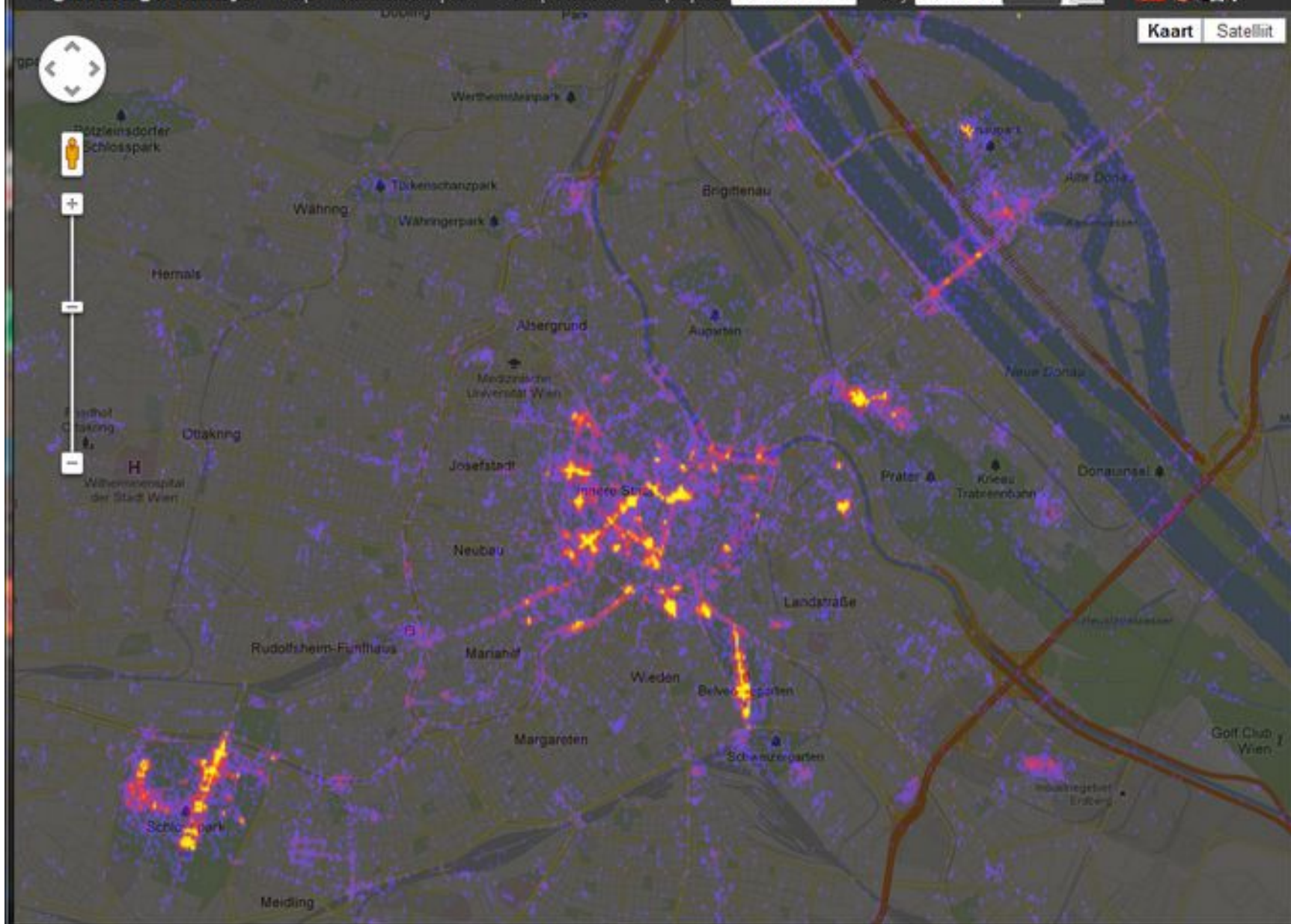
Throughout the centuries, the Town Hall Square has been used as a market square and gathering place. The square in front of the Town Hall was used for trading even before the Town Hall was built. It...

Start time 14:00 | End time 15:10 | Time spent: 12 hours and 04 minutes









# Input 1

- User interests:

likes(john,nightlife,0.6)

likes(john,sports,0.8)

likes(john,music,0.7)

likes(john,heavymetal,0.9)

dislikes(john,classicalmusic,0.9)

# Input 2

- **Object properties:**

type(omalley,bar,0.9)

activity(omalley,footballwatching,0.7)

popularity(omalley,1000)

type(crown,restaurant,1.0)

activity(crown,heavymetal,0.8)

popularity(crown,1500)

opentime(crown,12.00,0.9)

# Input 3

- Knowledge about the world:

`type(X,church,M) -> type(X,architecture,M*0.9)`

`type(X,bar,M) -> type(X,drinkingplace,M)`

`type(X,restaurant,M) -> type(X,drinkingplace,M*0.7)`

`activity(X,footballwatching,M) -> activity(X,sports,M)`

`type(X,fastfood,M) -> visitminutes(X,20,0.8*M)`

`type(X,bar,M) & M>0.75 -> openat12(X,0.85)`

`description(X,S) & contains_str(S,"paintings") & contains_str(S,"gallery")`

`->`

`type(X,artcollection,0.8)`

# Output

- **Recommendations:** numerical ranks for all tourism objects:

`rank(john,omalley,0.6)`

`rank(john,crown,0.5)`



# Reasoning tasks

- **Object identities**: are two objects A and B obtained from different sources actually equal?
- **Object types from content**: using title, abstract, source etc, calculate wheather the object is a city, a castle, a church, medieval, modern, a drama play, a classical music concert, a rock concert, ...
- **Generalised object types**: if we know that an object is a bar (with some confidence X), then it is also a nightlife spot (with some confidence Y)
- **Additional properties** like time of visit, opening times
- How well does an object **match user preferences**

# Probabilities?

There is a large number of probability-oriented theories and several reasoning systems, yet no “mainstream” probabilistic rule-based derivation algorithms exist

Fuzzy logic, probabilistic logic, Bayes networks, ....

Probabilistic datalog, probabilistic prolog, ...

Mycin, Emycin, Cadiag-2, ...

# Goal

Formulate a practical, correct and complete way to use probabilities in rules for the (tourism) recommender context, using object logic.

Metalogic:

0.9:  $\text{type}(X, \text{church}) \rightarrow \text{type}(X, \text{architecture})$

0.8:  $\text{type}(X, \text{fastfood}) \rightarrow \text{visitminutes}(X, 20)$

Object logic:

$\text{type}(X, \text{church}, M) \rightarrow \text{type}(X, \text{architecture}, M * 0.9)$

$\text{type}(X, \text{fastfood}, M) \rightarrow \text{visitminutes}(X, 20, M * 0.8)$

# Which kinds of probabilities?

Non-strict sets a la „blue“, „large“, ...

**Fuzzy logic** :  $p(A \vee B) = \max(p(A), p(B))$

0.95:  $\text{type}(X, \text{church}) \rightarrow \text{type}(X, \text{architecture})$

0.7:  $\text{type}(X, \text{theatre}) \rightarrow \text{type}(X, \text{architecture})$

Incomplete knowledge a la „not sure that“ ...

**Probabilistic**:  $p(A \vee B) = p(A) + p(B) - (p(A) * p(B))$

0.8:  $\text{type}(X, \text{bar}) \rightarrow \text{openat12}(X)$

**Object logic**:

$\text{type}(X, \text{church}, M) \rightarrow \text{type}(X, \text{architecture}, M * 0.9)$

$\text{type}(X, \text{fastfood}, M) \rightarrow \text{visitminutes}(X, 20, M * 0.9)$

# Object logic layers of interpretation

$\text{Pred}(t)$ :  $\text{Pred}(t)$  holds.

$\text{Pred}(t,m)$ :  $\text{Pred}(t)$  holds with a fuzzy measure at least  $m$ .

$\text{Pred}(t,m,c)$ : With confidence (probability) at least  $c$ ,  $\text{Pred}(t)$  holds with at least a fuzzy measure  $m$ .

$\text{Pred}(t,m,c,d)$ : The fact "with confidence (probability) at least  $c$ ,  $\text{Pred}(t)$  holds with at least a fuzzy measure  $m$ ," holds and depends on the set of clauses  $d$ .

# Examples

`bar(malloy,0.9,1)`: we are certain that malloy is bar  
with a fuzzy measure at least 0.9

`bar(crown,0.9,0.8)`: we are 0.8 confident that crown is  
a bar with a fuzzy measure at least 0.9

# Rule examples

$\text{bar}(X, M, C) \ \& \ M > L \ \rightarrow \ \text{openat12}(X, 1, C * 0.8):$

when we have confidence  $C$  in that  $X$  is a bar with a measure  $M$  at least  $L$ , we are  $C * 0.8$  confident that it is open at 12 with a measure 1.

optionally

$\text{bar}(X, M, C) \rightarrow \text{openat12}(X, 1, M * C * 0.8):$

example of a sure rule:

$\text{bar}(X, M, C) \rightarrow \text{can\_eat\_at}(X, M * 0.5, C):$



# Fuzzy part is easy

Use your own preferred function  $f$  and limits for fuzzy derivation

$\text{Pred}(X, M1) \ \& \ \text{Pred}(X, M2) \rightarrow \text{Pred}(X, f(M1, M2))$

$\text{Pred}(X, M) \ \& \ M > L \rightarrow \text{Pred}(X, f(M))$

Standard derivation rules in resolution hold, nothing is added.

We can enhance subsumption, provided  $f$  is monotonic:

$\text{Pred}(X, M1)$  subsumes  $\text{Pred}(Y, M2)$  iff  $Y = Xs$  and  $M1 \geq M2$ .

# Probabilistic part requires tracking

Recall  $P(t, M, C, D)$ :  $C$  is the probability and  $D$  is the set of facts on which the atom depends upon.

Always use rules of form

$$P(\dots, D_1) \& \dots \& P(\dots, D_n) \& A_1 \& \dots \& A_n \rightarrow \\ P(\dots, \text{union}(D_1, \dots, D_n))$$

where  $P$  atoms do contain probabilities and  
 $A_1 \dots A_n$  do not contain probabilities

# Multiplying probabilities

Generally the rules should have a form

$$P_1(t_1, M_1, C_1, D_1) \& \dots \& P_n(t_n, M_n, C_n, D_n) \rightarrow \\ P(t, M, f(M_1, \dots, M_n), g(C_1, \dots, C_n, D_1, \dots, D_n), \text{union}(D_1, \dots, D_n))$$

- In simple cases  $g(C_1, \dots, C_n, D_1, \dots, D_n) = C_1 * \dots * C_n$
- However, if  $\text{intersection}(D_1, \dots, D_n)$  is not empty,  $C_i$ -s corresponding to  $D_i$ -s with multiple occurrences should be used only once

# Cumulating evidence

Use evidence cumulating rule schema:

$\text{Pred}(X, M1, C1, D1) \ \& \ \text{Pred}(X, M2, C2, D2) \ \& \ \text{Empty}(\text{Intersection}(D1, D2))$

->

$\text{Pred}(X, \min(M1, M2), (C1+C2)-(C1*C2), \text{union}(D1, D2))$

# Cumulating evidence

Example: independent facts

- a)  $\text{bar}(X, M, C, D) \ \& \ M > 0.75 \rightarrow \text{openat12}(X, 1, C * 0.8, D)$
- b)  $\text{intitle}(X, \text{"allnight"}, M, C, D) \ \& \ M > 0.75 \rightarrow \text{openat12}(X, 1, C * 0.9, D)$
- c)  $\text{bar}(\text{malloy}, 1, 1, \{c\})$ .
- d)  $\text{intitle}(\text{malloy}, \text{"allnight"}, 1, 1, \{d\})$ .

a,c: e)  $\text{openat12}(\text{malloy}, 1, 0.8, \{c\})$

b,d: f)  $\text{openat12}(\text{malloy}, 1, 0.9, \{d\})$

giving for our case ( $0.8 + 0.9 = 1.7$ ,  $0.8 * 0.9 = 0.72$ ,  $1.7 - 0.72 = 0.98$ )

$\text{openat12}(\text{malloy}, 1, 0.98, \{c, d\})$

# Cumulating evidence

Example: dependent facts

f)  $\text{activity}(X, \text{heavymetal}, 1, 1, D) \rightarrow \text{activity}(X, \text{music}, 1, 1, D)$ .

g)  $\text{activity}(X, Y, M1, C1, D1) \ \& \ \text{likes}(U, Y, M2, C2, D2) \rightarrow$   
 $\text{fits}(U, X, 1, M1 * M2 * C1 * C2, \text{union}(D1, D2))$

a)  $\text{likes}(\text{john}, \text{music}, 1, 0.6, \{a\})$

b)  $\text{likes}(\text{john}, \text{heavymetal}, 1, 0.8, \{b\})$

c)  $\text{activity}(\text{crown}, \text{heavymetal}, 1, 1, \{c\})$ .

c,f: h)  $\text{activity}(\text{crown}, \text{music}, 1, 1, \{e\})$ .

g,a,h(cf): i)  $\text{fits}(\text{john}, \text{crown}, 1, 0.6, \{a, c\})$

g,b,c: j)  $\text{fits}(\text{john}, \text{crown}, 1, 0.8, \{b, c\})$

Cumulating prohibited, since i and j share c

# Ranking calculation in meta-logic

- Derive all open-at-time facts.
- Derive all independent addrank facts, using:

Popularity(X,P) -> addrank(X, pf(P))

Likes(X,Y,M1) & assoc(Z,Y,M2,C,D) ->  
addrank(X,Z, f(M1,M2,C),D)

Dislikes(X,Y,M1) & assoc(Z,Y,M2,C,D) ->  
addrank(X,Z, nf(M1,M2,C),D)

- Sum all maximal pos/neg addrank numbers for objects.
- Filter out objects which are open at time.
- Order by rank.



# Summary 1

Represent facts as  $P(t, M, C, D)$  where:

$M$  - fuzzy measure of  $P(t)$  holding

$C$  – confidence as probability of at least  $P(t, M)$  holding

$D$  – set of facts on which  $P(t, M, C)$  depends

Represent rules as

$P_1(t_1, M_1, C_1, D_1) \& \dots \& P_n(t_n, M_n, C_n, D_n) \&$

$M_1 > L_1 \& \dots \& M_n > L_n \& A_1 \dots \& A_m$

->

$P(t, M, f(M_1, \dots, M_m), g(C_1, \dots, C_n, D_1, \dots, D_n), \text{union}(D_1, \dots, D_n))$

# Summary 2

Add evidence cumulating rule

$\text{Pred}(X, M1, C1, D1) \ \& \ \text{Pred}(X, M2, C2, D2) \ \& \ \text{Empty}(\text{Intersection}(D1, D2))$

->

$\text{Pred}(X, \min(M1, M2), (C1 + C2) - (C1 * C2), \text{union}(D1, D2))$

Add extended subsumption

$\text{Pred}(X, M1, C1, D1)$  subsumes

$\text{Pred}(Y, M2, C2, D2)$

iff  $Y = Xs \ \& \ M1 \geq M2 \ \& \ C1 \geq C2 \ \&$

$D1$  is a subset of  $D2$

